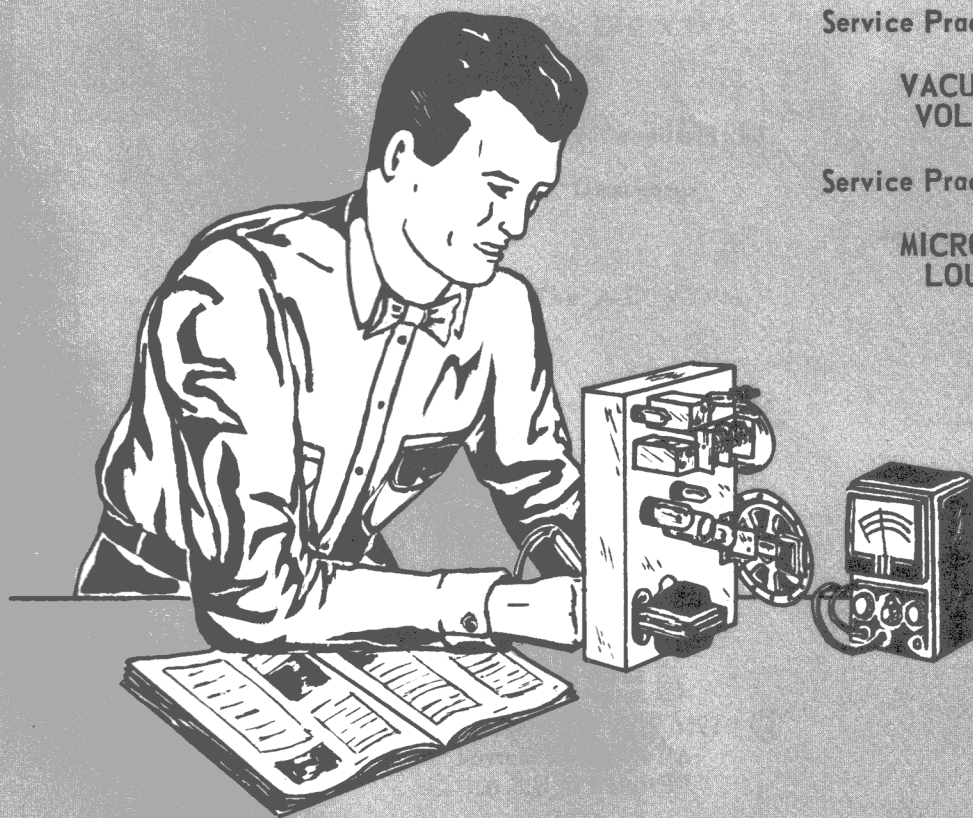


Study Group 13

ELECTRONIC FUNDAMENTALS



Service Practices 25:

VACUUM-TUBE
VOLTMETER

Service Practices 26:

MICROPHONES AND
LOUDSPEAKERS



RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York,

N. Y.

ELECTRONIC FUNDAMENTALS

SERVICE PRACTICES 25

VACUUM-TUBE VOLTMETER

- 25-1. The D-C VTVM
- 25-2. The Vacuum-Tube
 Ohmmeter
- 25-3. The A-C VTVM
- 25-4. The Crystal Probe



RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Service Practices 25

INTRODUCTION

A *vacuum-tube voltmeter* (VTVM) is a voltmeter that includes an electron tube among its working parts. The tube improves the measuring ability of the meter.

The vacuum-tube voltmeter has the following advantages:

1. It causes much less disturbance in the circuit under test.
2. It can measure small voltages accurately.
3. It can be adapted to measure large resistances accurately.
4. It can be fitted to measure high-frequency a-c voltages.

These four advantages are due to the high input impedance of the vacuum-tube voltmeter. The input impedance of the VTVM shown in Fig. 25-1 is about eleven megohms. It remains at the same high value for all settings of the range switch on the front panel of the meter.

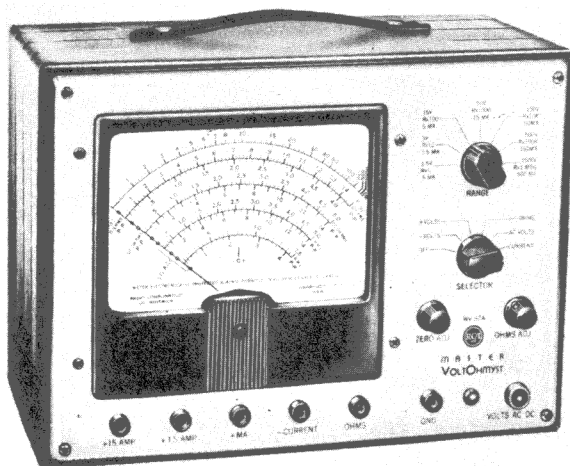


Fig. 25-1

The vacuum-tube voltmeter draws very little current from the circuit under test; it does not place a very heavy load upon the circuit being tested.

25-1. THE D-C VTVM

Basic Circuit. If the ordinary voltmeter shown in Fig. 25-2a were to be used to measure an unknown voltage, it would not have the advantages offered by the VTVM because it has a low input impedance. In order to provide a high input impedance, the voltmeter could be connected across the plate-load resistor of an electron-tube amplifier, as shown in Fig. 25-2b. A pair of leads connected on either side of the grid resistor of the tube would be used in place of the voltmeter leads in order to measure voltages.

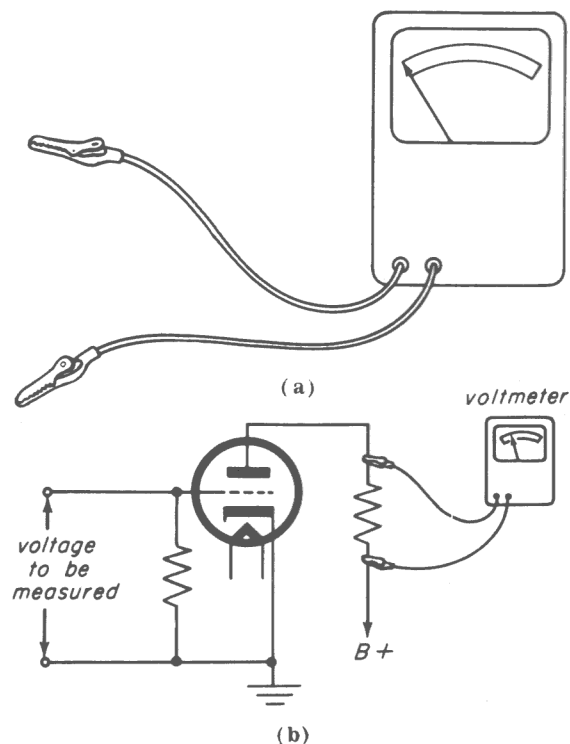


Fig. 25-2

As a result of this arrangement, the voltmeter can take advantage of the high input impedance of the amplifier. This makes it possible to draw very little current from the source of the voltage being measured. You have already learned, from your study of amplifiers, that no current flows from cathode to grid in the voltage amplifier and that current flowing from the voltage source through the grid resistor is small.

In other words, the amplifier circuit serves as a go-between, separating the ordinary voltmeter (which would draw current, if it were connected to a voltage source directly) from the circuit being tested. Although the voltmeter draws current from the plate load of the amplifier, the amount of current drawn can be taken into account and compensated for.

The circuit shown in Fig. 25-2b is a simple vacuum-tube voltmeter, but not a practical one. Unlike practical vacuum-tube voltmeters, this circuit has gain. Furthermore, it has certain disadvantages not found in the practical vacuum-tube voltmeters that we consider in later sections of this booklet.

For instance, the amplifier of Fig. 25-2 is capable of receiving only one volt at its input before it overloads. But a VTVM must be capable of measuring more than a few volts. To overcome this disadvantage, a voltage divider is placed in the grid circuit, as shown in Fig. 25-3. The 10-megohm im-

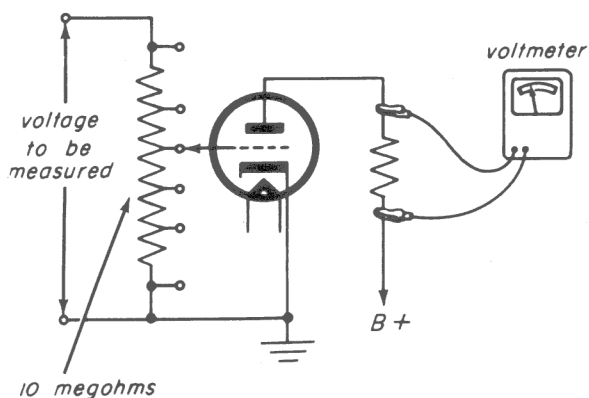


Fig. 25-3

pedance of the divider is presented to a circuit under test, and the grid of the tube is tapped down on the divider so that no more than about one volt is ever applied to the tube. Thus, the range of voltages that can be measured is extended. The divider acts as a range switch in a VTVM. It presents the same impedance (10 megohms) to a circuit under test, regardless of what range of voltage it is set to measure.

But the 10-megohm grid resistor sets up a contact-bias voltage at the grid of the tube. This bias registers on the meter along with the voltage being measured, producing an error in the meter indication. This error cannot easily be compensated for in the calibration of the meter scale because it is not the same at each setting of the range switch, and it varies with the resistance of the source of voltage being measured. As you know from your study of amplifiers, contact-bias voltage is greatest when the grid resistance is largest. The grid resistance of the amplifier shown in Fig. 25-3 is largest when the range switch is set for the lowest voltage range. As the switch is set to higher ranges, the grid resistance decreases—although the resistance presented to a circuit under test remains unchanged.

The resistance of the circuit under test parallels the 10-megohm divider. Therefore, the amplifier's grid resistance is modified by the internal resistance of the source of voltage being measured. For this reason, the error voltage varies with the resistance of the source of voltage being tested.

Also, slight variations in the B+ voltage applied to the amplifier change the readings registered upon the voltmeter connected across the amplifier's plate load. For example, when B+ increases, more plate current flows. This, too, results in inaccurate readings. Since slight fluctuations of B+ cannot be prevented, they must be offset.

Degenerative Circuit. Employment of a degenerative amplifier avoids the two disadvantages just described. A degenerative

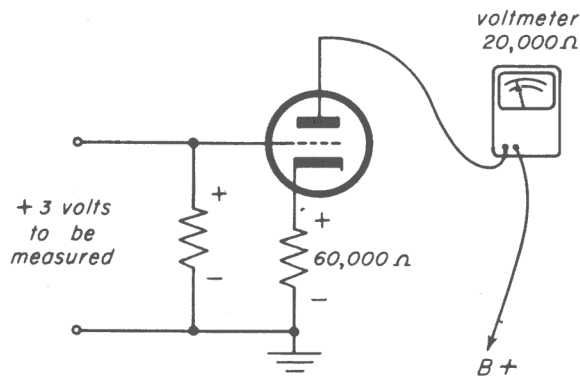


Fig. 25-4

voltmeter circuit is shown in Fig. 25-4. You can recognize that it is a degenerative amplifier by the large cathode resistor. The meter remains in the plate circuit, but no plate-load resistance other than the meter is required. The internal resistance of a current-drawing meter is an adequate plate load for an electron tube.

When a positive voltage is applied to the grid, plate current increases, causing the voltage dropped across the cathode resistor to increase. Since the value of the resistor is high, the increased voltage drop is considerable. The polarity of the voltage dropped across the cathode resistor opposes the polarity of the voltage applied between grid and ground; the applied voltage is partially cancelled out so that the net voltage (between grid and cathode) is much less than the voltage of the circuit being measured. This cancellation effect is degeneration. The circuit is designed so that no applied positive voltage (up to the maximum voltage intended to be applied for measurement) can make the grid voltage zero with respect to the cathode. At most, the grid can become between one and two volts negative.

Contact bias cannot develop at a grid that is sufficiently negative with respect to cathode. Contact-bias voltage develops due to the drift of electrons from cathode to grid. So long as the voltage applied to the grid is about 1.5 volts negative, the electrons are repelled away from the grid.

Another precaution taken in the design of VTVM's to minimize contact bias is operation of the tube filaments below their rated voltages. For example, 5.7 volts may be

applied to the filament in place of 6.3 volts. As a result, fewer electrons are emitted by the cathode. It is possible to operate the degenerative amplifier tube in this way because very little plate current flows. The large cathode resistor limits it. The cathode is not called upon to deliver a large quantity of electrons to support plate current.

The degenerative amplifier compensates for slight variations in B+ by means of a regenerative effect that takes place with respect to applied plate voltage. When a small variation in the value of B+ applied to the plate causes plate voltage to decrease, plate current tends to decrease. In the degenerative circuit, such a decrease in plate current causes a considerable decrease in the voltage dropped across the cathode resistor. The voltage between grid and cathode becomes less negative enough to cause plate current to increase as much as the reduced B+ tends to decrease it. Thus, the current flowing through the plate load resistor, and consequently, the voltage output dropped across the resistor, does not vary with small variations in B+.

So much does the cathode resistor limit current flow through the tube that the change in plate current caused by a change of grid voltage is approximately equal to the voltage E_x to be measured at the grid divided by the resistance R_k .

$$\Delta I_p = \frac{E_x}{R_k}$$

The plate current of the tube almost follows Ohm's law as it would if the voltage being measured were applied directly to the cathode resistor and there were no tube in the circuit. This fact makes easy the approximate calculation of the tube's output voltage across the current-drawing meter, as we shall see.

Unlike the circuits shown in Fig. 25-2 and 3, the degenerative amplifier has no gain. It actually has a loss. The internal resistance of the current-drawing meter is 20,000 ohms. The cathode resistor is 60,000 ohms. If 3 volts is applied to be measured at the grid of the tube, the plate current flow will change by 50 microamperes:

$$\Delta I_P = \frac{E_x}{R_k} = \frac{3}{60,000} = 50 \mu\text{a}$$

Fifty microamperes flowing through the 20,000-ohm meter causes a voltage drop of one volt.

$$E = IR = 50 \mu\text{a} \times 20,000 \text{ ohms} = 1 \text{ volt}$$

The meter registers 1 volt where 3 volts is applied to the amplifier. This discrepancy is easily taken care of in the calibration of the meter scale by labeling the 1-volt deflection point 3 volts.

But this circuit has a serious disadvantage. A certain steady plate current must always flow through the meter, even while no voltage-to-be-measured is present at the grid. This has two undesirable results. The meter pointer does not rest at zero; and a large voltage drop is always present across the current reading meter so that the meter must be set to a high voltage range and, therefore, its pointer will not move much when a small voltage-to-be-measured is applied at the grid of the amplifier tube.

When the circuit is changed to eliminate the steady current flowing in the meter movement, we have arrived at a practical VTVM circuit. This final obstacle is overcome with the circuit of the famous RCA

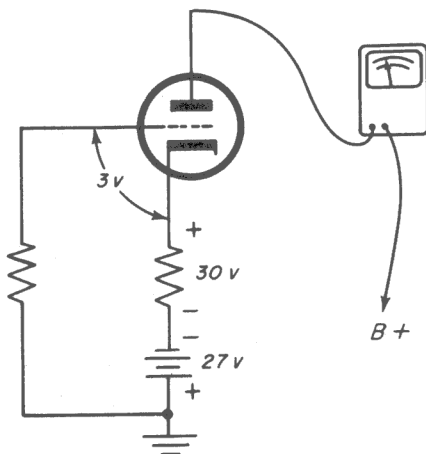


Fig. 25-5

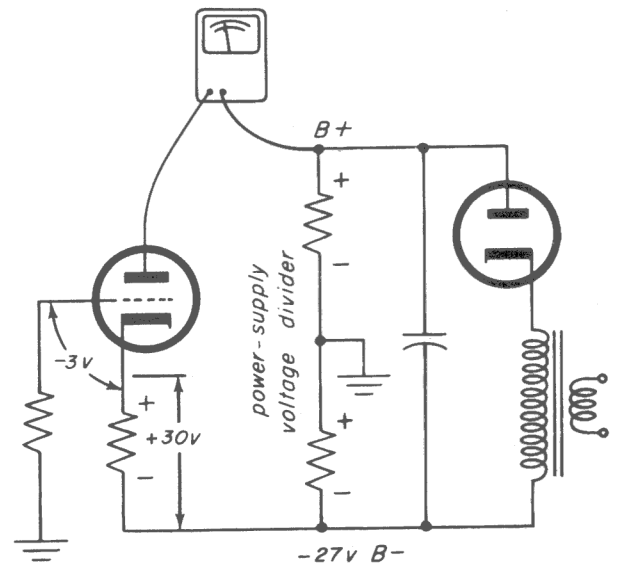


Fig. 25-6

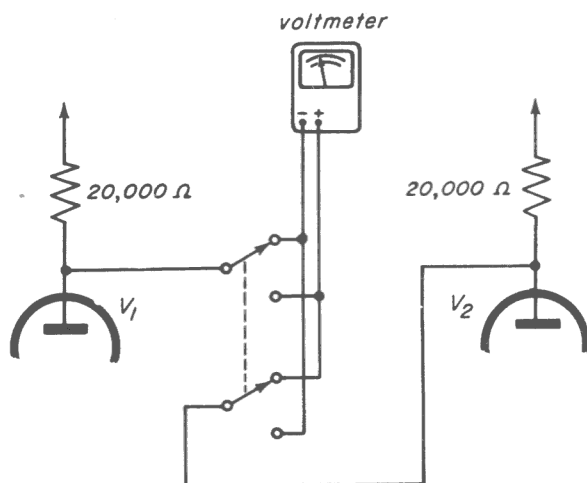
VoltOhmyst[®], which consists of two degenerative amplifiers in balance.

In order to fully understand the circuit of the VoltOhmyst[®], we must consider the bias requirements of the degenerative amplifier. Assume that the steady plate-current flow desired for the circuit of Fig. 25-4 is 500 microamperes and that, according to the tube characteristics, a bias voltage of 3 volts is required for class A operation with 500 microamperes of d-c plate current. How can this bias be applied? The current of 500 microamperes flowing through the 60,000 ohm cathode resistor must result in a voltage drop of 30 volts across the resistor. This would place the grid at 30 volts negative with respect to cathode. Needed is a bucking voltage to cancel out 27 volts, leaving the grid 3 volts negative with respect to cathode. The manner of applying a bucking voltage is shown in Fig. 25-5. The 30 volts dropped across the cathode resistor is positive at the cathode end of the resistor and negative at the ground end. To buck this voltage out, a 27-volt battery, negative toward the cathode, is inserted between cathode and ground. The cathode resistor is returned to a point 27 volts negative instead of to zero volts ground. The resultant bias is 3 volts. A tap on the power-supply voltage divider can be used in place of the negative terminal of a battery. Figure 25-6 shows how the bucking voltage is applied from a power-supply voltage divider.



The power supply is arranged to apply 36 volts B+ to the plates of the tubes, and a

When a negative voltage to be measured is applied to the grid of V_1 , the plate voltage of V_2 falls and that of V_1 rises. A nega-



switch shown in
position to read + volts

Fig. 25-8

tive difference voltage is applied across the current-drawing volt-meter. The pointer would be driven off scale were not the leads to the current-drawing meter reversed. Reversal is accomplished by means of a reversing switch (Fig. 25-8). The switch is a front-panel control. Its two positions are labeled +VOLTS and -VOLTS. The correct position is chosen by the meter user, depending upon whether the voltage to be measured is positive or negative.

The pointer can be made to rest at center scale in position to deflect one way for a negative input voltage and the other way for

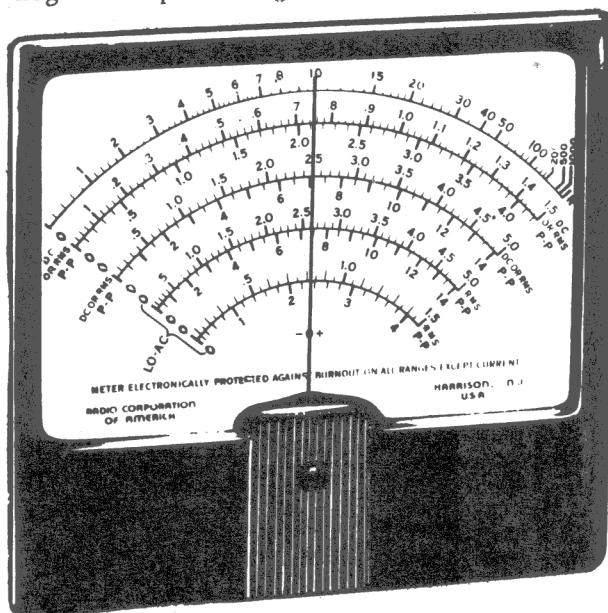


Fig. 25-9

a positive input. The balancing rheostat control can be rotated until the pointer is center-positioned on the zero marker, as shown in Fig. 25-9. The reversing switch can be used to determine whether the pointer will go left for positive input and right for negative input, or the reverse.

So far, we have not considered the makeup of the current-drawing meter. It is an ammeter movement with a series-dropping resistor that is needed to convert an ammeter to a volt-reading meter (Fig. 25-10). The meter in the VoltOhmyst® circuit of Fig. 25-7 must deflect full scale with two volts applied to its terminals. The meter of Fig. 25-10 is so designed. A two-hundred micro-ampere movement deflects full scale with one volt applied and draws 200 micro-amperes; it has an internal resistance of 5,000 ohms. The series-dropping resistor needed to have the meter deflect full scale with two volts applied is also 5,000 ohms. With the series resistor in place, 200 micro-amperes flows through both the resistor and the movement; one volt drops across each. The 5,000-ohm series resistance is in the form of an 8,000-ohm rheostat, which can be adjusted to 5,000 ohms. In practice, it is adjusted so that the meter deflects full scale with three volts applied to the input of the VTVM. The series combination forms a 5,000 ohms-per-volt meter, permanently set to the two-volt range and having a total internal impedance of 10,000 ohms. The electron-tube circuit acts as a go-between—going between this meter, with its 10,000-ohm input impedance, and the circuit under test. The input impedance of the electron tube circuit and, therefore, that of the VoltOhmyst®, is 11 megohms.

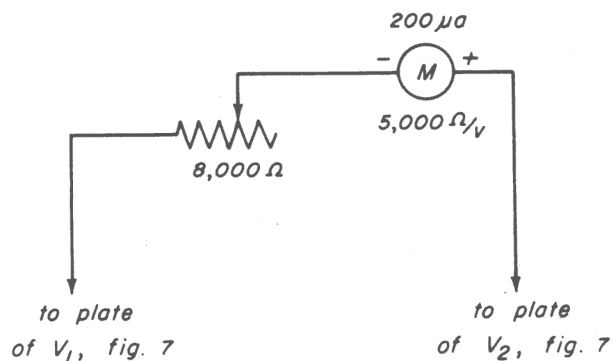


Fig. 25-10

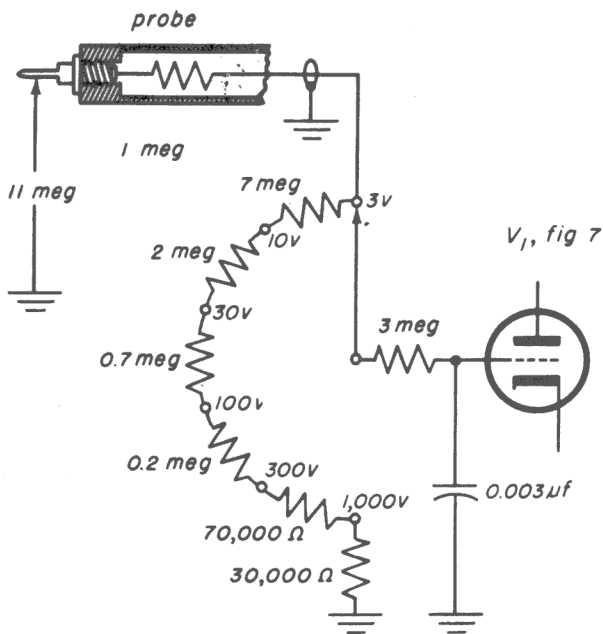


Fig. 25-11

The 11-megohm input circuit of the VoltOhmyst® is shown in Fig. 25-11. Reading from the point of the meter probe towards the grid of V_1 , we encounter first a one-megohm resistor located in the tip of the probe. then the 10-megohm range-switch voltage divider. The resistance of the circuit totals 11 megohms from probe tip to ground. Continuing towards the grid of V_1 , we encounter a three-megohm resistor and a 0.003- μ f capacitor. The 3-megohm resistor has no effect upon the input impedance of the VTVM because it does not return to ground. It connects to the grid of V_1 , and is series, not in parallel, with the input to the grid. Together with the capacitor, the 3-megohm resistor forms a filter that filters out all a-c voltage, leaving only d.c. at the grid of V_1 . The voltage-divider selector switch is arranged so that normally no more than 3 volts d.c. reaches the grid of V_1 . However, even if an excessively large voltage-to-be-measured is applied to the grid, the resulting current flow through the meter movement is limited to a safe value by the electron-tube circuit. The movement is protected against overload damage.

Sensitivity. Let's compare the sensitivity of a VTVM to that of an ordinary current-drawing voltmeter. Assume that a source of 2 volts has an internal impedance of 25,000 ohms. This could readily be the case at

various points in a radio receiver. Let us see what error results when this voltage is measured.

The internal impedance of a source of voltage forms a series voltage divider with the internal impedance of a meter (Fig. 25-12). If the 5,000 ohms-per-volt meter set to the three-volt range measures 2 volts, the voltage divider will form as shown at *a*. This is the kind of meter movement employed in the VoltOhmyst®. Used directly, the internal impedance of the meter is 15,000 ohms. That of the source is 25,000 ohms. Voltage divides across the two impedances; the meter indicates 0.75 volts for 2 volts. Now suppose the voltage is measured with a very high-quality current drawing meter, such as your kit meter—a 25,000 ohms-per-volt meter. The meter is set on the three-volt range. As a result, the meter has an internal impedance of 75,000 ohms. It indicates 1.5 volts for 2 volts (*b*). The VoltOhmyst® has an internal impedance of 11 megohms; it indicates 1.997 volts for 2 volts under the specified conditions (*c*).

Moreover, the VoltOhmyst® indicates the same voltage regardless of which range of voltages it is set to measure, because its internal impedance is the same on all ranges. Ordinary meters have a higher impedance at higher voltage-range settings. The readings, under the specified conditions would be more accurate at higher voltage-range settings with ordinary meters. However, the needle deflection is smaller on higher ranges; it is more difficult to read the indication. Also, the ordinary meters are more accurate with low-impedance voltage sources. For example, B+ can be measured quite accurately with a 5,000 ohms-per-volt meter.

Observe that good meter sensitivity is a question of how small a voltage the instrument can detect from a source of how high an internal impedance. Sensitivity is not alone a question of how small a voltage can be detected.

The high input impedance of an electron tube, and not the tube's amplifying ability, gives the VTVM its improved sensitivity.

Isolation Probe. In addition to a high-input impedance, it is well for a d-c voltmeter

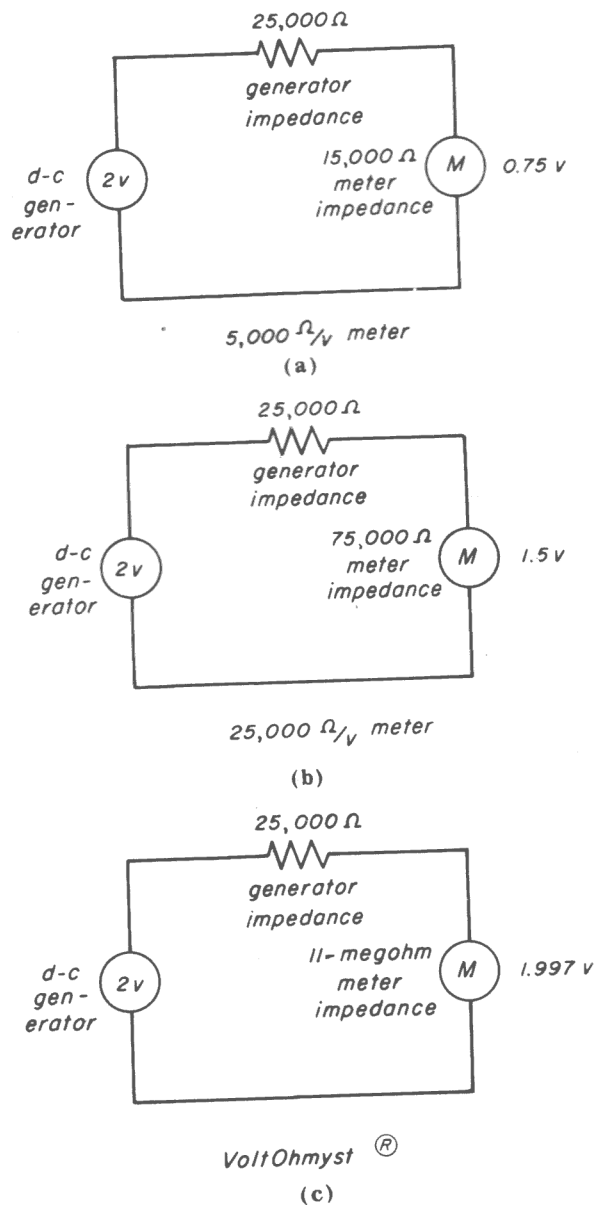


Fig. 25-12

to have low internal capacitance across its input terminals. When the probe and ground lead of a meter are placed across a circuit to measure d-c voltage, whatever capacitance is present across the input of the meter is thereby paralleled with the circuit under test. If the circuit happens to be a tuned circuit, resonant frequency shifts, due to the added capacitance. The circuit is then not operating in a normal way. The d-c voltage registered on the meter is not that which is present under normal conditions.

The one-megohm isolating resistor that is mounted in the d-c probe of the VoltOhmyst[®] and which raises the input im-

pedance of the instrument from 10 to 11 megohms also acts to reduce the input capacitance to about $1\mu\text{f}$. The resistor at the very tip of the probe can separate, from a circuit under test, all the stray shunt capacitance that is present across the meter input (Fig. 25-13). Stray capacitance is formed between the two input leads to the meter, the input terminal connector, the wiring, etc. The stray capacities combine in parallel and have a reactance that is measurable in ohms and a phase angle that characterizes the ohmic reactance as being capacitive. The isolating resistor is in series with this reactance. It has a zero phase angle (characteristic of resistance) and a very large ohmic value. The value in ohms of the resistor is so large that it, much more than the ohms of the capacitive reactance, determines the impedance makeup of the series combination. The phase angle of the series combination is much closer to zero than is that of the capacitive reactance alone. Consequently the capacitance represented by the resistor and stray capacities combined in series is much less than the capacitance of the stray capacities taken alone.

Such an isolating probe cannot function with a current-drawing meter. It is usable only with a VTVM, because the voltage to be measured divides across the resistor and the input impedance of the meter. With the VoltOhmyst[®], one eleventh of the input voltage is thus prevented from reaching the grid of the input tube where it can be measured. This is not a serious loss; it can be made up for in the calibration of the meter. (Here again, the high input impedance of the VTVM accounts for improved measuring ability.) The internal impedance of a current-drawing meter causes much of the measured voltage

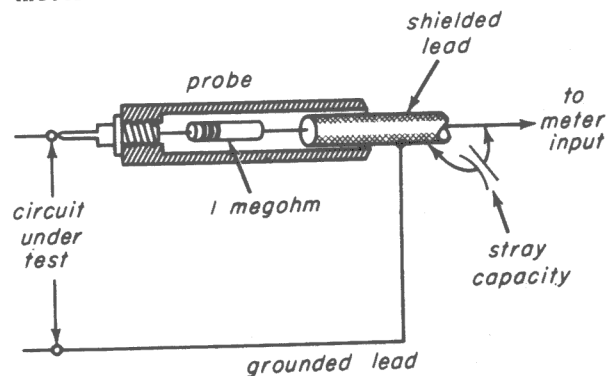


Fig. 25-13

to be lost across the isolating resistor. For example, with a 25,000 ohms per volt meter on the 3-volt range, the internal impedance is 75,000 ohms. Ninety-two percent of the voltage to be measured would be lost across a one megohm isolating resistor.

25-2. THE VACUUM-TUBE OHMMETER

The VoltOhmyst® and other vacuum-tube multimeters contain a voltage-divider type ohmmeter. The initial adjustment, made before using this ohmmeter, differs with respect to your kit meter as follows. The ohms scale of your kit meter reads right to left, and that of the VTVM reads left to right. The pointer of your kit meter is initially adjusted to point at the zero mark at the right-hand end of the dial (full scale) with the test leads shorted. With the test leads not shorted, your kit ohmmeter points to the infinity mark at the left-hand end of the dial. The pointer of the vacuum-tube ohmmeter is adjusted to point to infinity at the right end of the dial (full scale) with the leads not shorted. With the leads shorted, the pointer points toward zero at the left end of the dial. The zero-adjustment balancing rheostat is adjusted to cause the pointer to point directly at the zero mark.

The schematic diagram, Fig. 25-14, shows how a vacuum-tube voltmeter can be adapted to measure resistance. A 3-volt battery is employed to apply voltage to the input of the vacuum-tube voltmeter through a standard resistor. This voltage causes the meter pointer to move to full scale. The resistor to be measured (R_x) is connected across the input terminals of the balanced amplifier. It is in series with the standard resistor. The meter reads full scale (3 volts) with no resistor to be measured in place, because there is no resistance in series with the standard resistor and, therefore, no current can flow from the battery to cause a voltage drop across the standard resistor. (The voltage range-switch voltage divider is not in its place at the input terminals of the VTVM.)

Depending upon the value of the standard resistor, a certain voltage will drop across the resistor being measured. This voltage will register on the meter dial. A particular voltage indication represents a particular

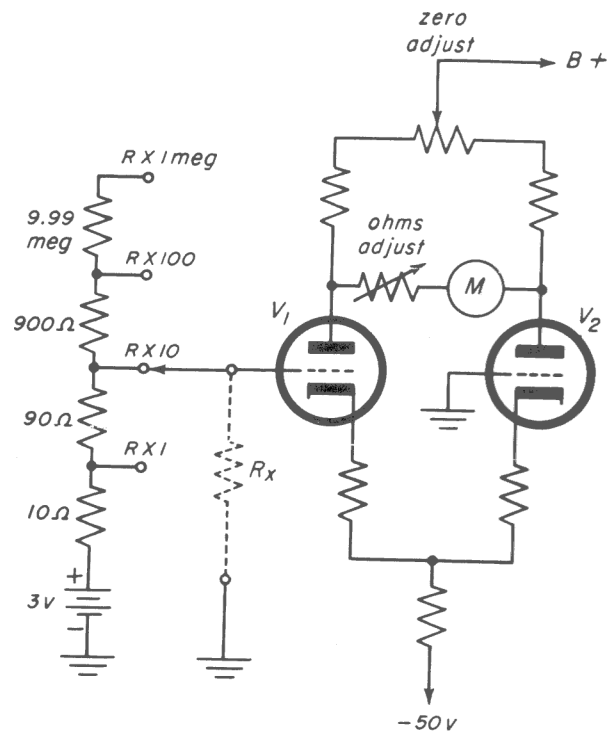


Fig. 25-14

measured resistance when a particular standard resistor is in place. Assume that the standard resistor is 10 megohms. An unknown resistor is placed in position to be measured and the pointer comes to rest at two volts. Two volts out of a total of three volts is across the unknown resistor. For such division of voltage to take place, the unknown resistor must be two times as large as the known standard resistance. The unknown resistance must be twenty megohms.

The battery voltage divides, half and half, across the standard and the unknown resistance when the unknown equals the standard. When the two are equal, the pointer comes to rest at center-scale deflection. The ohmmeter shows 10 ohms at center scale with a 10-ohm standard. This is the $R \times 1$ position of the range switch. The switch functions to increase the standard to 100 ohms in the $R \times 10$ position, and so on, until in the $R \times 1$ meg position the standard is 10 megohms.

The $R \times 1$ megohm range permits accurate measurement of very large resistances. And, again, it is the high input impedance of the VTVM that enables this very high ohmmeter range to be incorporated in the vacuum-tube multimeter. The VoltOhmyst® indicates 100 megohms clearly and accurately. When a

resistance of 100 megohms is being measured, the instrument is accurately measuring 2.7 volts across megohms. The VTVM, because of its high impedance, does not place a shunt across the resistance being measured.

25-3. THE A-C VTVM

The schematic diagram of a VoltOhmyst[®] model that incorporates a d-c vacuum-tube voltmeter, a vacuum-tube ohmmeter, and an a-c voltmeter is shown in Fig. 25-15. We have already considered the d-c voltmeter and ohms section. In some vacuum-tube multimeter designs, the a-c meter is not a VTVM; the movement is employed directly to form a current-drawing a-c voltmeter. This is sufficient for measuring power voltages. For measuring a-c signal voltages in radio receivers and audio amplifiers, a vacuum-tube a-c voltmeter is more desirable. The a-c voltmeter of the circuit shown in Fig.

25-15 is a VTVM. A simplified schematic of only the a-c section is shown in Fig. 25-16. The a-c voltage to be measured is rectified in V_1 , and the resulting d-c voltage is applied to the input grid of the balanced amplifier in the vacuum-tube multimeter. The voltage divider at the input grid of the balanced amplifier is the same one that is employed with the d-c voltage section. The divider serves the same purpose as for d-c measurement, but it has a much larger total resistance because of the presence of an additional series resistance, R_4 .

Contact potential develops across the diode, V_1 . This voltage reaches the input grid of the balanced amplifier, where it would cause a reading to register on the meter if the effect of the contact potential were not balanced out. It is balanced out by a corresponding contact voltage that is developed across V_{2B} and applied to the remaining

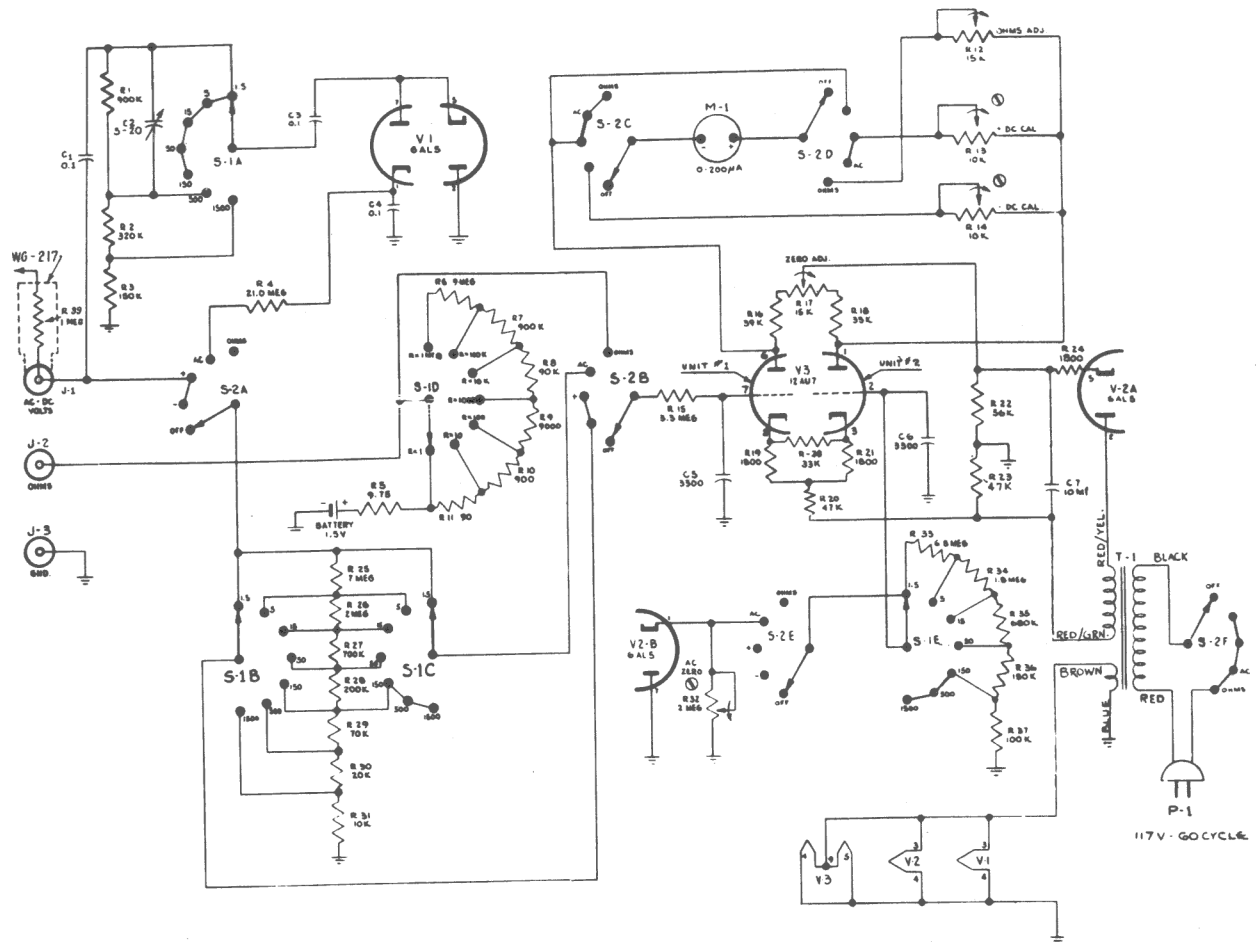


Fig. 25-15

grid of the balanced amplifier. The only function of V_{2B} is to provide this correction voltage. The plate voltage of each of the two tubes in the balanced amplifier changes a like amount due to diode contact voltage and, as a result, no difference in potential exists across the meter movement; the movement does not register contact-potential error.

The contact voltage developed on the diode plates does not change with the internal impedance of the source of a-c voltage being measured because the source is isolated from the diode by C_1 and C_3 . D-C

current in the diode cannot reach the source of voltage being measured.

The contact voltage results from flow of this current through the voltage divider resistance of the range switch — R_{33} to R_{37} . The resistance of the range-switch divider is constant regardless of the impedance of the source of voltage measured. Therefore, the diode contact voltage is constant regardless of the source impedance. Because it is constant, it can be compensated for in the manner described.

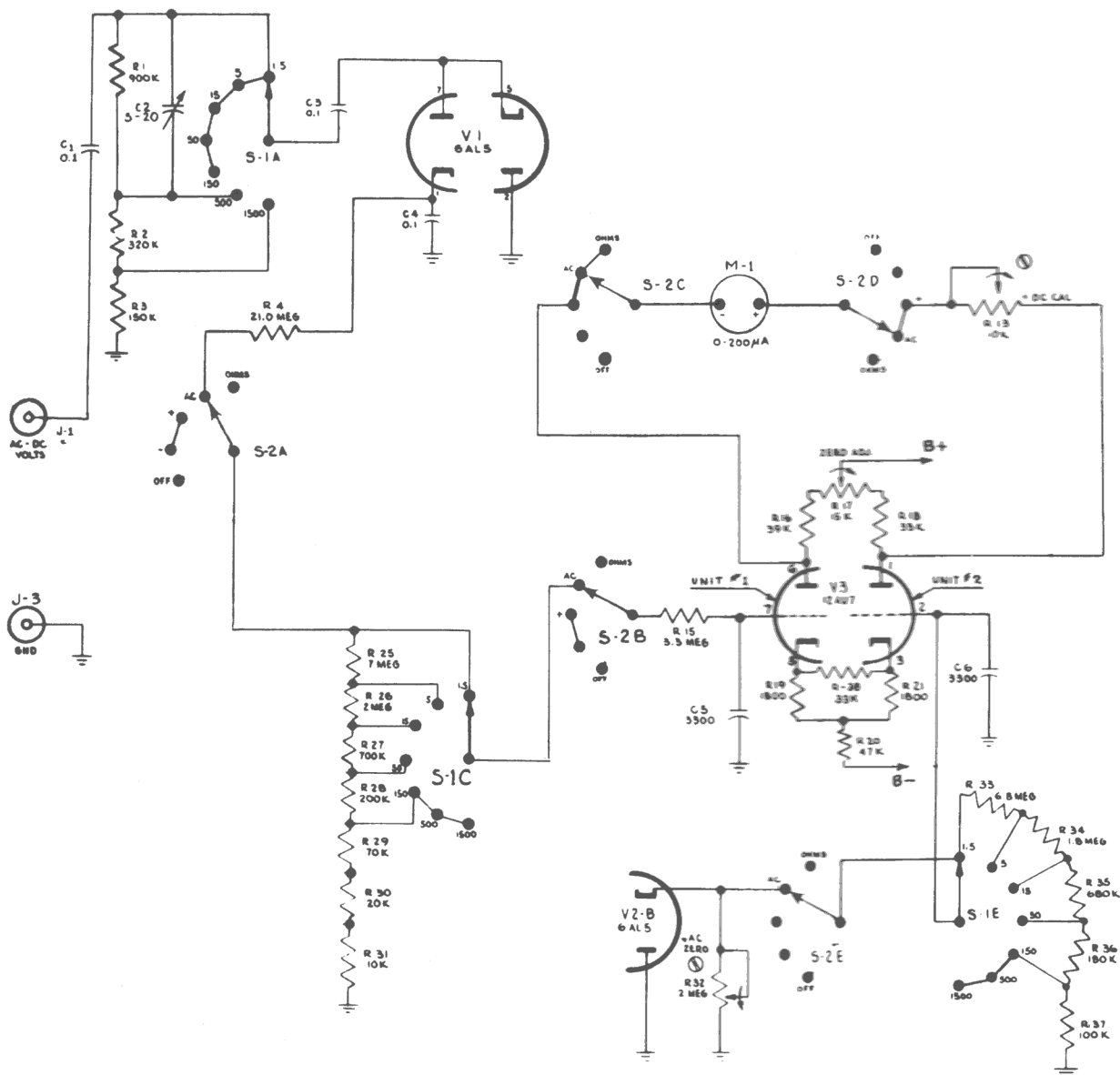


Fig. 25-16

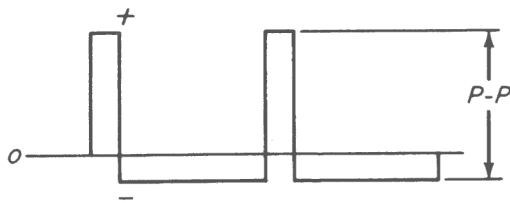


Fig. 25-17

The diode rectifier built around V_1 is a peak-to-peak rectifier. It produces a d-c output voltage that is equal to the difference in voltage between the maximum positive and the maximum negative peaks of the waveform of an a-c voltage being measured. It is advantageous that the meter responds to peak-to-peak values and not peak values of a-c voltage when a nonsymmetrical waveform of voltage is to be measured. A nonsymmetrical waveform (Fig. 25-17) is one that has a positive amplitude (above the zero reference line) that is not equal to its negative amplitude (below the zero reference line). Voltmeters that respond to peak amplitude rectify one half (either the positive half or the negative half) of an a-c waveform of voltage. Which half gets rectified is a matter of chance. When the waveform is nonsymmetrical, the reading for the rectified positive half is different from the reading for the rectified negative half. Peak-to-peak meters rectify both halves and measure the resulting d-c voltages, added together. Thus, the peak-to-peak meter measures the amplitude of a waveform from its positive to its negative tips and not from the instantaneous zero voltage to either tip.

In any case, the d-c meter that functions in conjunction with the rectifier must have a very high input impedance if *full* peak or peak-to-peak amplitude is to be measured. If the input impedance of the d-c meter is low, it imposes a load upon the rectifier, which prevents the rectifier from developing a d-c output equal to the full amplitude of the a-c input.

The peak-to-peak rectifier circuit of Fig. 25-16 is shown, alone, in Fig. 25-18a. C_1 is a blocking capacitor that blocks out any d-c voltage, present together with the a-c voltage to be measured.

One cycle for the applied a-c waveform is shown in Fig. 25-18. As the instantaneous voltage goes negative from zero, V_{1a} conducts, since its cathode becomes more negative than its plate. Current flows from the right hand plate of C_3 , which is zero potential at first, through V_{1a} and R_a back to the negative going left-hand plate of C_3 . C_3 charges with the polarity shown. When the instantaneous negative voltage reaches its peak value, the charge on C_3 has reached a corresponding value in volts. The capacitor stops

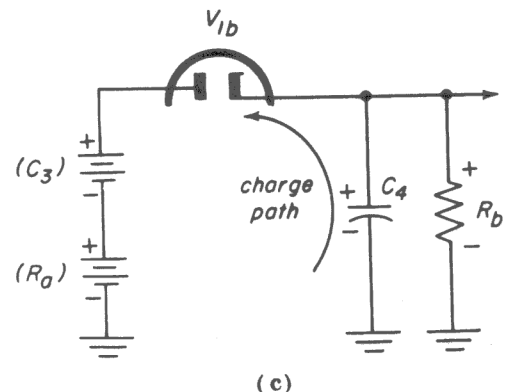
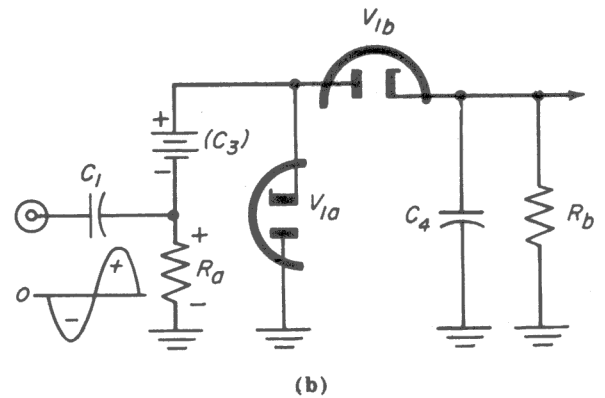
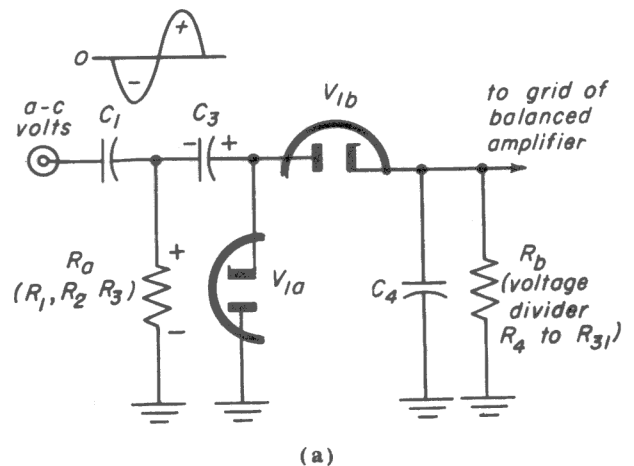


Fig. 25-18

reaches its negative peak. C_3 cannot discharge while the changing voltage again approaches zero because, at this time, the cathode of V_{1a} is more positive than the plate, which returns through ground and R_a to the negative source voltage. The voltage at the source is approaching zero and has a less negative amplitude than does the right hand plate of C_3 .

The plate of V_{1b} is more positive than its cathode. C_3 tends to discharge very, very slowly through R_a , R_b , and V_{1b} . C_3 discharges very little through this path, because it includes the 30-megohm resistance (R_b) of the range-switch voltage divider. The divider can have such a large resistance only because the input impedance of the balanced amplifier is so high. Thus, C_3 charges to the full negative peak of the input waveform and holds the charge.

Then the instantaneous voltage of the input waveform goes positive. At b in Fig. 25-18 we show that the positive voltage is rising across R_a and is in series with the voltage of the charged capacitor, C_3 (here represented by a battery of equivalent voltage).

At C of Fig. 25-17, the instantaneous positive voltage across R_a has reached its positive peak and is represented by a second battery. The two imaginary batteries represent the positive peak voltage and the negative peak voltage of the input waveform. The two voltages are added in series and are directly across C_4 through V_{1b} . C_4 charges through V_{1b} to the peak to peak voltage of the waveform. This voltage is applied to be measured to the input grid of the balanced amplifier.

The input impedance of the a-c meter section of this vacuum-tube multimeter is the input impedance of the peak-to-peak rectifier — about one megohm resistance shunted by 70 $\mu\mu\text{f}$ capacity. For source impedances of 100 ohms or lower (the range of output impedances of signal generators), the meter can accurately measure a-c voltages from 30 cps to 3 megacycles. For a source impedance of about 1,000 ohms, the maximum frequency that can be accurately measured is 500 kc.

The resistance, R_b is actually a series combination consisting of a 21-megohm calibration resistor (R_4 of Fig. 25-15) in series with the several resistors of the range-switch voltage divider. The value of the calibration resistor is chosen so that approximately 30% of the output of the peak-to-peak rectifier drops across the range-switch resistance, there to be measured. The value of the calibration resistor is accurately chosen so that the d-c scale of the meter face will directly register the rms portion (30% approximately) of the peak-to-peak voltage from the rectifier. The d-c scale serves two purposes. It indicates the value of d-c voltage and the rms value of a-c voltage. An additional scale is calibrated to show what peak-to-peak voltage values correspond to the rms values shown on the d-c scale. The instrument *responds* to peak-to-peak voltage and *reads* both rms and peak-to-peak voltage.

It is the reactance of the 70- $\mu\mu\text{f}$ stray shunt capacity across the 1-megohm input impedance of the a-c vacuum-tube meter that limits the meter's sensitivity at high frequencies. The capacitive reactance, measured in ohms, gets small as frequency gets high. The small reactance of the capacity shunts out the 1-megohm input resistance. From the formula

$$X_c = \frac{1}{2 \pi f c}$$

we find that the reactance of 70 $\mu\mu\text{f}$ is about 1,000 ohms at 2 megacycles. At 2 megacycles, the input impedance of the meter is shunted by 1,000 ohms.

25-5. THE CRYSTAL PROBE

Location of the rectifier part of an a-c meter in the test probe greatly reduces the shunt capacity and extends the frequency response of the instrument. Most of the 70 $\mu\mu\text{f}$ shunt capacity exists between the inner and outer conductors of the test lead. When the rectifier is in the test probe, no length of test lead is present between voltage source

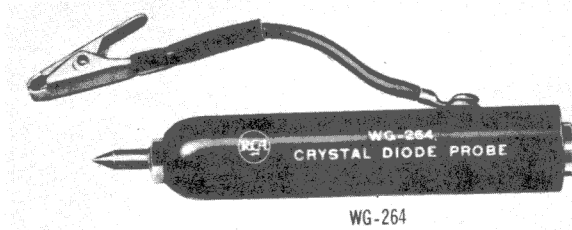


Fig. 25-19

and rectifier input. Such rectifier probes (Fig. 25-19) are used in conjunction with a d-c VTVM. They can have a low input shunt capacity, and a frequency response extending past 200 megacycles.

Crystal rectifiers instead of electron tubes are usually employed in rectifier probes because, with an electron-tube diode, it is necessary to include filament wires in the test lead from meter to probe. Another disadvantage of the tube is that it develops contact bias. The tube has the advantage that it accomplishes more complete rectification than the crystal. This is because a tube conducts no current backwards (plate to cathode) whereas a crystal has a finite back

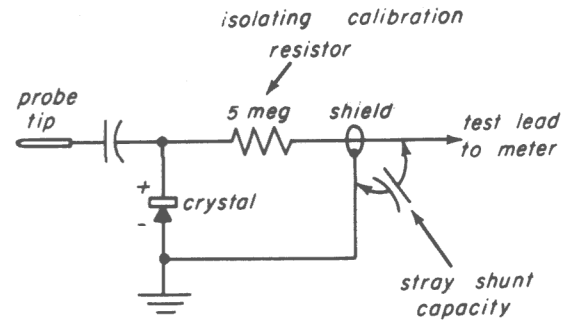


Fig. 25-20

resistance and so conducts some current backwards.

A peak responding crystal diode probe is shown schematically in Fig. 25-20. The 5-megohm resistor serves to isolate the shunt capacity of the test lead from the rectifier circuit. It is also a calibrating resistor with value chosen so that rms voltage is directly read on the d-c voltage scale of the VTVM. The low frequency response of such probes does not extend as low as does the response of the previously described *built-in* rectifier. The low-frequency response of the probe is limited by the input capacitor, which has a large reactance at low frequencies. Typically, the probe response is from 50 kc to 250 mc.